Chemical variation in tourmalines from south-west England

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Summary. Forty-eight samples of tourmaline from the granitic rocks of south-west England have been analysed by emission spectrography for Fe, Mn, Mg, Ca, Ti, Na, F, Li, Sc, V, Cr, Co, Ni, Cu, Ga, Rb, Sr, Zr, Sn, and Sc. The tourmaline reflects the fractionation trends of the rocks from which it comes in the proportion of Mg, Ca, Ti, and certain trace elements it contains and is considered likely to have been a primary product of the magma. Textural evidence that indicates a later development is interpreted as recrystallization, possibly at low temperature, with little change in chemical composition. Hydrothermal tourmaline has a distinctive chemical composition, being higher in Mg, Ca, Sr, and Sn and lower in Fe, Mn, and F and also tending to have a higher Cr, V, Ni, and Sc content. The chemical composition of the tourmalines is used to show that some quartz-tourmaline rocks are the product of extreme fractionation and are not completely tourmalinized granites. Parti-coloured tourmaline is shown to be the result of hydrothermal growth.

THE geology of the granites of south-west England is reviewed comprehensively by Exley and Stone (1964). A series of post-kinematic high-level plutons emplaced in end-Carboniferous time form the surface expression of what is probably one interconnected mass of granite extending from Dartmoor to the Scilly Isles. The predominant rock-types are coarse porphyritic biotite granites containing varying proportions of potassium feldspar megacrysts. Finer-grained non-porphyritic varieties do occur and also granites characterized by the presence of lithium micas or fluorite. Tourmaline is a common accessory mineral of the granites and in the present study the trace element content of tourmaline from different environments is investigated and related to the mode of origin of the samples.

Sample preparation and spectrographic analysis

Tourmaline-rich concentrates were obtained from crushed samples of the rock using an isodynamic magnetic separator. Each concentrate was then carefully hand-picked with the aid of a binocular microscope and all impurities and composite grains removed. The pure tourmaline was crushed to pass through a 230-B.S.S.-mesh sieve.

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Spectrographic analyses were carried out using a Hilger and Watts Large Quartz spectrograph, type E742. All determinations were made in triplicate except for lithium, rubidium, and caesium for which sufficient sample material was available for only a limited number of single determinations. Line densities were measured using a Joyce Loebl Mark IIIB recording microdensitometer and a method incorporating emulsion calibration, background correction, and internal standards was used throughout. Working curves for all elements except iron were constructed from a series of samples of a natural tourmaline containing known additions of 'Specpure' chemicals. Completely synthetic standards were used for iron and these also gave favourable results for the United States Geological Survey reference rocks, G-1 and W-1, apparently indicating that the method used was free from gross errors due to 'matrix effects'.

Results

The results of the spectrographic analyses are given in Tables I and II together with the environment from which the samples originated and their appearance in thin section. It was hoped that each of the groups of samples from different environments would prove to have its own characteristic features of chemical composition. The only group that may be unmistakably recognized on this basis is that of a later generation, the hydrothermal tourmalines, which will be discussed in detail later. However, in the earlier generation there are differences in the concentrations of some elements that, although not sufficient to distinguish any one group, do appear to vary systematically between certain groups.

Variation in composition with fractionation. The range of variation of magnesium, titanium, and calcium content within several of the groups is shown in fig. 1. It may be seen that each of these elements decreases systematically in the tourmalines in the series from granites, aplites, pegmatites, and certain quartz–tourmaline rocks. If the granites, aplites, and pegmatites are considered to form a fractionating magma series then a decrease in the magnesium, titanium, and calcium content of these rocks would be expected to take place with increasing fractionation and the decreases found in the tourmalines may be said to closely reflect the fractionation trends of the rocks from which they come. On this basis samples from certain quartz–tourmaline rocks have a composition consistent with their being extreme members of the fractionation series. The concentration of all of the other elements determined,

TABLE I. Trace elements, in ppm, in tourmalines from south-west England; tr., *ca.* 5 ppm. *E*, environment from which the sample originated: G, granite; A, aplite; P, pegmatite; Q, quartz-tourmaline rock; R, greisen; V, tourmaline vein; H, hydro-thermal; C, contact zone; T, topaz fels.

Col., colour in thin section: Y, yellow; B, blue; Z, well-developed zoning; YBR, predominately yellow with blue rims and patches; BYC, predominately blue with yellow central patches

No.	*E.*	*Col.*	Li	Sc	V	Cr	Co	Ni	Cu	Ga	Rb	Sr	Zr	Sn	Cs
25/P	G	Y	78	42	55	105	27	16	4	52	7	29	172	23	8
33/P	G	Y	—	61	76	37	38	32	2	45	—	12	155	19	—
48/P	G	Y	—	54	27	5	17	17	7	56	—	18	120	26	—
50/P	G	Y	—	41	21	9	20	21	7	73	—	11	116	77	—
CD4	G	Y	—	73	51	20	19	30	5	54	—	16	80	27	—
CD10	G	Y	—	57	37	17	17	23	3	49	—	26	76	15	—
89/P	G	Y	235	14	18	10	10	25	5	60	10	13	108	12	9
55/P	G	Y	—	15	16	7	20	29	4	50	—	21	91	24	—
7/P	A	Y	—	74	32	7	13	16	8	78	—	16	112	16	—
11/P	A	Y	—	23	38	43	5	37	21	74	—	24	131	10	—
13/P	A	Y	—	62	Tr.	Tr.	38	37	7	75	—	19	60	Tr.	—
14/P	A	Y	194	24	Tr.	Tr.	45	33	7	100	Tr.	20	64	Tr.	11
18/P	P	Y	316	53	Tr.	Tr.	21	17	7	107	4	Tr.	95	Tr.	22
20/P	P	Y	—	31	25	4	22	26	7	72	—	20	81	29	—
56/P	P	Y	356	21	12	Tr.	17	Tr.	10	93	11	Tr.	92	Tr.	15
57/P	P	YBR	245	16	18	5	23	15	7	68	2	11	110	32	7
51/P	Q	BYC	294	15	19	6	26	10	4	80	Tr.	29	99	24	9
53/P	Q	BYC	319	14	18	4	33	19	5	59	Tr.	30	105	29	9
54/P	Q	BYC	—	11	24	Tr.	33	19	5	80	—	30	85	22	—
63/P	Q	YBR	—	17	18	6	10	12	7	73	—	51	66	28	—
66/P	Q	Y	446	13	22	67	20	53	10	61	5	34	156	37	10
75/P	Q	BYC	1640	10	26	7	9	24	4	93	Tr.	65	81	43	8
58/P	R	Y	—	16	16	8	14	23	4	55	—	16	150	57	—
87/P	R	YBR	—	10	35	12	10	31	10	31	—	107	120	63	—
88/P	R	Y	583	10	10	7	11	19	4	48	Tr.	16	146	15	9
9/P	V	YBR	—	25	62	17	30	46	5	100	—	34	64	15	—
10/P	V	Y	—	28	80	68	41	41	10	69	—	25	107	16	—
12/P	V	Y	—	12	41	22	10	15	35	59	—	55	112	23	—
23/P	V	YBR	—	38	84	44	39	55	13	105	—	25	86	26	—
27/P	V	YBR	—	62	148	27	34	56	8	100	—	64	90	82	—
T5	V	YBR	161	18	63	12	25	23	3	47	2	95	105	73	8
73/P	V	Y	—	20	56	15	16	25	10	80	—	15	130	18	—
65/P	V	YBR	1020	13	49	4	18	25	11	41	2	33	68	125	9
69/P	V	Y	472	10	37	9	19	25	7	69	2	29	110	37	7
80/P	V	BZ	—	13	21	6	9	9	2	73	—	17	77	99	—
T3	H	BZ	1250	16	41	8	19	25	13	49	15	144	110	161	8
26/P	H	BZ	118	60	265	75	40	100	75	63	Tr.	168	282	425	6
49/P	H	BZ	382	73	156	50	20	52	10	75	Tr.	180	124	300	9
96/P	H	BZ	853	45	68	26	11	33	8	47	Tr.	195	295	78	4
70/P	H	B	—	15	67	25	14	72	17	31	—	185	61	84	—
T2	H	B	308	36	165	6	8	52	10	66	Tr.	165	80	470	8
15/P	C	Y	165	22	32	4	35	41	6	106	Tr.	25	82	13	N.D.
99/P	C	Y	—	77	20	13	7	36	5	87	—	23	105	10	—
17/P	C	YBRZ	—	20	121	17	9	54	9	65	—	75	116	53	—
301	P	Y	274	35	28	7	21	20	4	86	2	13	97	27	13
77/P	T	Y	—	16	33	22	27	31	4	54	—	105	109	19	—
CD15B	—	B	—	10	N.D.	8	15	55	8	54	—	122	118	59	—
CD15Y	—	Y	—	25	N.D.	8	15	41	45	57	—	16	140	29	—

TABLE II. Minor elements (percentage) in tourmalines from south-west England

No.	F	Fe	Mn	Mg	Ca	Ti	Na
25/P	0·64	9·3	0·14	1·3	0·22	0·4	1·09
33/P	0·85	9·1	0·16	1·3	0·29	0·44	1·03
48/P	0·76	11·2	0·28	0·82	0·23	0·36	1·14
50/P	0·57	10·5	0·36	0·93	0·30	0·26	1·15
CD4	0·86	9·6	0·22	1·13	0·39	0·27	1·03
CB10	0·62	9·9	0·18	0·87	0·35	0·39	1·11
89/P	0·92	11·2	0·23	0·27	0·29	0·3	1·12
55/P	0·83	9·7	0·22	0·61	0·30	0·32	1·01
7/P	0·83	10·2	0·23	0·46	0·16	0·31	1·21
11/P	0·73	8·7	0·18	0·65	0·19	0·32	0·99
13/P	0·67	11·4	0·19	0·74	0·21	0·20	1·21
14/P	0·66	11/5	0·22	0·81	0·15	0·18	1·26
18/P	0·9	11·5	0·29	1·01	0·18	0·41	1·45
20/P	0·78	9·8	0·21	0·56	0·13	0·28	1·21
56/P	0·62	11·1	0·37	0·2	0·1	0·2	1·37
57/P	0·81	9·6	0·3	0·64	0·14	0·25	1·14
51/P	0·78	9·9	0·22	0·3	0·13	0·15	0·98
53/P	0·6	10·5	0·18	0·27	0·11	0·11	1·1
54/P	0·72	11·2	0·26	0·1	0·12	0·12	1·35
63/P	1·05	11·2	0·21	0·35	0·11	0·17	1·84
66/P	0·73	9·9	0·19	0·64	0·17	0·3	1·21
75/P	1·04	10·7	0·22	0·22	0·23	0·1	1·26
58/P	0·69	11·4	0·28	0·35	0·24	0·34	1·17
87/P	0·68	14·0	0·32	0·33	0·23	0·43	0·95
88/P	0·87	9·5	0·31	0·47	0·2	0·24	1·06
9/P	0·74	9·5	0·2	1·3	0·18	0·24	1·05
10/P	0·67	9·0	0·23	1·6	0·16	0·28	1·11
12/P	0·57	10·2	0·21	0·86	0·23	0·30	1·19
23/P	0·69	9·0	0·25	2·2	0·38	0·35	1·46
27/P	0·71	10·9	0·23	2·32	0·29	0·38	1·39
T5	0·49	9·8	0·24	1·25	0·26	0·32	1·19
73/P	0·75	8·9	0·25	2·0	0·15	0·31	1·0
65/P	1·25	7·0	0·08	1·13	0·1	0·11	0·93
69/P	0·99	9·9	0·19	0·92	0·12	0·29	1·11
80/P	0·94	10·1	0·28	0·23	0·11	0·05	1·13
T3	0·38	9·0	0·12	0·97	0·26	0·2	1·25
26/P	0·33	8·7	0·07	2·36	0·39	0·29	1·18
49/P	0·58	9·5	0·33	2·65	0·48	0·4	1·39
96/P	0·47	8·3	0·07	2·0	0·98	0·47	1·08
70/P	0·38	5·0	0·06	2·72	0·51	0·11	0·95
T2	0·39	7·6	0·12	2·95	0·49	0·16	1·14
15/P	0·75	9·8	0·27	1·31	0·16	0·21	1·11
99/P	0·95	14·0	0·23	0·29	0·23	0·3	1·07
17/P	0·69	9·0	0·18	1·08	0·19	0·21	1·15
301	0·68	9·6	0·53	0·59	0·8	0·29	1·09
77/P	0·76	15·4	0·21	0·46	0·26	0·29	1·13
CD15B	0·65	12·8	0·24	1·3	0·38	0·13	1·26
CD15Y	0·83	10·9	0·35	0·59	0·16	0·35	1·26

Key to Tables I and II. (National grid references given in brackets)

25/P	Coarse porphyritic biotite granite. Pedn men Du, Sennen Cove, Land's End granite (S.W. 348263).
33/P	Coarse porphyritic biotite granite. Cripples Ease quarry. Land's End granite (S.W. 501368).
48/P	Coarse porphyritic biotite granite. Staple Tor, Dartmoor granite (S.W. 543760).
50/P	Granite. Merrivale quarry, Dartmoor (S.W. 546754).
CD4	'Buff' fine-grained granite. Castle an Dinas quarry, nr. Penzance, Land's End granite (S.W. 487347).
CD10	Fine-grained granite. As above.
55/P	'Quartz porphyry'. Quarry nr. Sennen Cove, Land's End granite (S.W. 365261).
89/P	Granite. St. Michael's Mount (S.W. 514298).
7/P	Aplite. Porthmeor Cove, Land's End granite (S.W. 426377).
11/P, 13/P, 14/P	Aplites. North side Great Zawn, nr. Zennor, Land's End Granite (S.W. 420375).
18/P	Pegmatite. Road cutting. Knills Steeple, St. Ives', Land's End granite (S.W. 516387).
20/P	Pegmatite. Quarry, as above.
56/P	Pegmatite. Tremearne, Tregonning-Godolphin granite (S.W. 611266).
57/P	Feldspar pegmatite. Tresayes, St. Austell granite (S.W. 996585).
51/P	Light-coloured quartz–tourmaline rock. Roche Rock, St. Austell granite (S.W. 992596).
53/P	Dark-coloured quartz–tourmaline rock. As above.
54/P	Quartz–tourmaline rock; acicular tourmaline, little quartz. As above.
63/P	Quartz–tourmaline rock. Hendra clay pit, St. Austell granite (S.W. 959566).
66/P	Quartz–tourmaline rock containing kaolinised feldspars. Melador clay pit, St. Austell granite (S.W. 927554).
75/P	Quartz–tourmaline rock. Blackpool clay pit, St. Austell granite (S.W. 927554).
58/P	Greisen, at margin of pegmatite. Tresayes, St. Austell granite (S.W. 996585).
87/P	Greisen. Lee Moor clay pit, Dartmoor granite (SX570625).
88/P	Greisen. St. Michael's Mount (S.W. 514298).
9/P, 10/P	Quartz–tourmaline veins. South side Great Zawn, nr. Zennor, Land's End granite (S.W. 420374).
12/P	Quartz–tourmaline vein. North side Great Zawn, nr. Zennor, Land's End granite (S.W. 420374).
23/P	Tourmaline with quartz in vein. Pedn men Du, Sennen Cove, Land's End granite (S.W. 348263).
27/P	Tourmaline vein at centre reddened granite. As above.
T5	Schorl vein. Sheltor, Dartmoor granite.
73/P	Tourmaline. Exact locality unknown.
65/P	Tourmaline vein. Restrowrack clay pit, St. Austell granite (S.W. 953564).
69/P	Tourmaline vein. Melador clay pit, St. Austell granite (S.W. 927554).
80/P	Tourmaline from vug in vein. Trelavour clay pit, St. Austell granite (S.W. 960573).
T3	Luxullianite, St. Austell granite.
26/P	Reddened granite. Pedn men Du, Sennen Cove, Land's End granite (S.W. 348263).

49/P   Reddened granite. Staple Tor, Dartmoor granite (S.X. 540756).
96/P   Vug in granite. Nr. Morvah, Land's End granite (S.W. 413364).
70/P   Quartz vein. Melador clay pit, St. Austell granite (S.W. 927554).
T2   Schorl. Locks Cross, Sherberton Common, Dartmoor granite (S.X. 695735).
15/P   Margin of aplite vein in hornfels. North side Great Zawn, nr. Zennor, Land's End granite (S.W. 420375).
99/P   Tourmaline at granite contact. Mousehole, Land's End granite (S.W. 260470).
17/P   Tourmaline pod at granite contact. North side Great Zawn, nr. Zennor, Land's End granite (S.W. 420375).
301   Pegmatitic pocket in granite. Tregarden quarry, Luxulyan, St. Austell granite (S.X. 054592).
77/P   Topazfels. St. Mewan Beacon, St. Austell granite (S.W. 986535).
CD15B   Blue marginal zone from tourmalines in reddened granite. Castle an Dinas Quarry, nr. Penzance, Land's End granite (S.W. 487347).
CD15Y   Yellow central zone from tourmalines as above.

including iron and manganese, does not vary systematically throughout the series. However, scandium, chromium, vanadium, and zirconium do tend to be higher in the tourmalines from the granites and lowest in those from the quartz–tourmaline rocks, which again is the distribution that would be expected if predominantly controlled by fractionation.

The chemical evidence suggests that the composition of the earlier generation of tourmaline is influenced by magmatic fractionation and it would therefore seem likely that this tourmaline was formed at the same time as the crystallization of the magma. There is considerable textural evidence that indicates that part at least of this tourmaline is not of primary origin. Brammall and Harwood (1925) describe tourmaline replacing mats of biotite and enveloping zoned plagioclase whilst Exley and Stone (1964) give an example where prisms of tourmaline in the fine porphyritic biotite granite of Godolphin Hill are shown to be optically continuous with skeletal networks of this mineral in megacrysts of potash feldspar. A possible explanation is that although the tourmaline was the primary product of the consolidation of the magma some has undergone extensive recrystallization but apparently with little change in chemical composition. If most of the tourmaline in the granites was formed as the result of a metasomatic process acting on the feldspars and biotite then a large-scale introduction of such elements as boron would have to be envisaged and the tourmaline produced might have been expected to be closer in composition to the hydrothermal tourmalines.

The recrystallization of the primary tourmaline need not necessarily have taken place at high temperature and pressure. Frondel and Collette

(1957) quote examples of the synthesis of tourmaline at 400° C and 10 bars pressure and authigenic tourmaline is recorded by Krynine (1949) as being formed in completely unmetamorphosed sediments. The growth of tourmaline in the Godolphin Hill granite is very similar in habit to the extreme development of an authigenic tourmaline, growing as it does from one end of well developed prisms of tourmaline. Tourmaline exhibits piezoelectric properties and the development of terminal
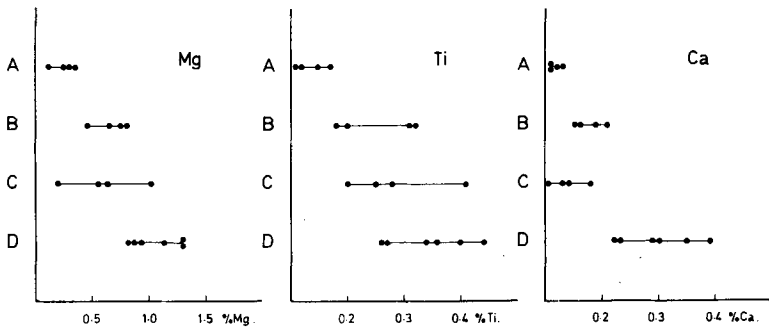

Fig. 1. Variation of Mg, Ti, and Ca in tourmalines from different environments. (Origin of samples, A: quartz–tourmaline rocks; B: aplites; C: pegmatites; D: granites.)

overgrowths on the crystal prisms in the granite may perhaps have been stimulated by changes in temperature and pressure giving rise to polar charges on the crystals.

Hydrothermal tourmaline. There are two distinct generations of tourmaline in the granitic rocks of south-west England (Exley and Stone, 1964). The earlier generation is the more widespread being a characteristic accessory mineral in most of the granites and a description of its modes of occurrence in the Dartmoor granite is given by Brammall and Harwood (1925). It varies in colour from yellow to brown in thin section and zoning is not often well developed. The later generation is blue-green in thin section and often forms aggregates of zoned acicular crystals sometimes growing on corroded nuclei of the earlier generation of tourmaline. It is found associated with both kaolinized and reddened granites and in, or close to, joints. A well-known example of its occurrence is in the altered granite, luxullianite. Wells (1946) described luxullianite as the product of the arrested pneumatolytic modification by boric emanations of a porphyritic alkali granite and Brammall and Harwood (1925) refer to reddened granites
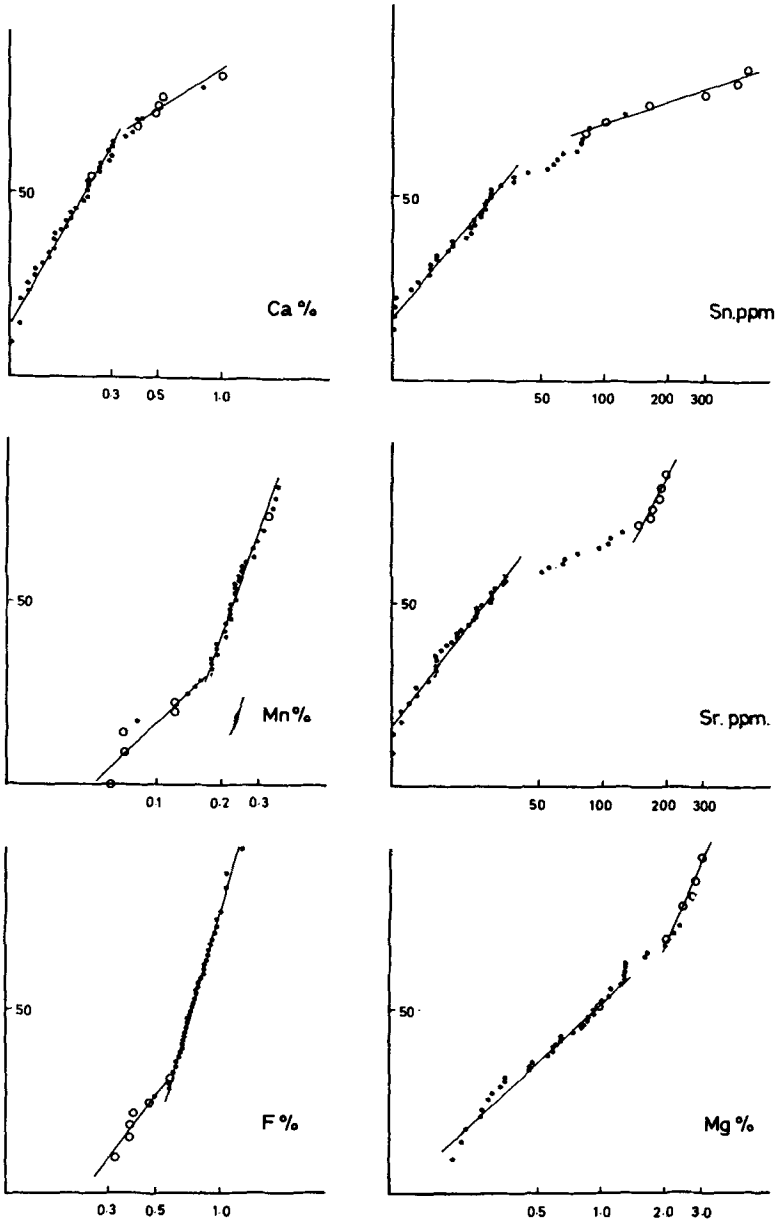
Fig. 2. Cumulative frequency diagrams for Ca, Mn, F, Mg, Sn, and Sr in tourmalines
from south-west England. (O: hydrothermal tourmaline.)

as the product of autopneumatolysis. There seems to be little doubt that this tourmaline is formed during an alteration process and this, together with its striking similarity in habit to tourmaline grown in hydrothermal syntheses (Smith, 1949; Frondel and Collette, 1957), suggests that the term hydrothermal may be conveniently used to describe it. This implies crystallization from a fluid phase without limitation as to whether liquid or gaseous and avoids the implications of order of crystallization that such terms as secondary convey.

The chemical analyses of hydrothermal tourmaline reveal that it has a distinctive chemical composition and this may be demonstrated by use of the cumulative frequency plot as described by Tennant and White (1959). The cumulative frequency plot may be considered as a form of histogram drawn on probability paper so designed that for a single population of samples the plot of cumulative percentage of frequency against concentration will yield a straight line if the frequency distribution is normal. Similarly if the logarithm of concentration is used, as was done throughout this study, a straight line will result if the frequency distribution is log-normal. When more than one population of samples is present more than one straight line may be obtained.

The cumulative frequency plot for fluorine is shown in fig. 2. It may be seen that fluorine ranges in concentration from 0·22 to 1·25 %. The majority of samples fall on a straight line i.e. the distribution of fluorine in these samples is log-normal. There is a deviation from this straight line at its lower end and another distinct population made up of the hydrothermal samples may be observed. Thus hydrothermal tourmalines can be said to form a population significantly lower in fluorine than the general population. Further cumulative frequency plots reveal that hydrothermal tourmalines are significantly lower in iron and manganese and higher in magnesium, calcium, strontium, and tin than the general population. Other trace elements do not show such clear-cut divisions although higher than average values for chromium, vanadium, nickel, and scandium are found in the hydrothermal tourmalines. A selection of the cumulative frequency plots is given in fig. 2. Thus hydrothermal tourmaline may be readily distinguished from the other tourmalines on the basis of its chemical composition.

Parti-coloured tourmaline. Brammall and Harwood (1925), describing the earlier generation of tourmaline, state that plates of parti-coloured (brown and blue) tourmaline, optically continuous throughout, are common. Yellow tourmaline may also sometimes be seen with an outer rim of blue tourmaline. One such example (CD 15) was found in a

reddened granite at Castle an Dinas quarry near Penzance. By careful hand-picking separate samples of both the inner yellow and outer blue tourmaline were obtained and analysed. The results reveal marked differences in their composition. The blue rim shows a close affinity to the hydrothermal tourmalines in composition, being distinctly higher in calcium, magnesium, strontium, and tin content than the yellow tourmaline, and is interpreted as a hydrothermal growth on the pre-existing yellow crystals. With this information in mind a careful examination of thin sections of samples from tourmaline veins, where the crystals of parti-coloured tourmaline are most commonly found, shows that all stages in the development of the blue patches can be observed. They are the result of the complete infilling of cavities and imperfections in the yellow crystals by blue needles of tourmaline. Supporting evidence for this hydrothermal growth is provided by the chemical analyses and cumulative frequency plots. It may be seen (fig. 2), particularly in the case of strontium and tin, that whereas the cumulative frequency distributions form two distinct populations of samples some samples fall between the two populations. It is found that all the samples observed to have yellow coloured tourmaline grains with blue patches in them plot between the two populations. This is taken to indicate that they form a third population in which each member is made up of a mixture of the two other forms of tourmaline. This relationship is further demonstrated in a study of the strontium:calcium ratio in tourmalines (Power, 1966).

Quartz–tourmaline rocks. The quartz–tourmaline rocks of the St. Austell district were taken by Flett (1909) to be the final product of the tourmalinization of the granite following on from further alteration of the luxullianite type. Where some signs of the original minerals of the granite may still be seen in the quartz–tourmaline rocks there seems to be no doubt that this is the case. However, in the specific example of Roche Rock there is no evidence that it was ever a normal granite and Hatch, Wells, and Wells (1949) suggest that it may represent a magma fraction drastically enriched in 'fugitives'. The chemical composition of the tourmaline from Roche Rock convincingly confirms this view. Not only does it have all the attributes of an extreme member of a fractionation series but it also has none of the features of composition shown to be characteristic of hydrothermal tourmaline. The chemical composition of tourmaline from quartz–tourmaline rocks is therefore an important factor in determining the geological origin of these rocks.

Previous trace element analyses of tourmalines

The trace element content of tourmalines has previously been investi-
gated in samples from San Diego by Warner (1935) and from Elba by
Carobbi and Pieruccini (1947). The analyses in both these works are of
a qualitative nature and both mainly attempt to correlate the presence
of various elements with the colour of the crystals. Both analysed alkali
tourmalines and the results are not directly comparable with those
obtained for the iron-rich tourmalines of south-west England. Butler
(1953) gives four semi-quantitative trace element analyses for tourma-
lines from south-west England that do not differ greatly from those
given in this work except that he records considerably more gallium.
Staatz, Murata, and Glass (1955) show a systematic variation in the
trace element composition of tourmaline with its position in a pegmatite
and explain this in terms of a single pegmatitic fluid crystallizing in a
closed system. This evidence of the control of fractionation on the dis-
tribution of trace elements in tourmaline provides supportf or the exis-
tence of a similar control in the granitic rocks of south-west England.

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